Solutions for improving the bearing capacity of wet, weak resource roads used by the Canadian forest industry

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ABSTRACT
Hundreds of kilometres of unpaved roads are built each year by the Canadian forest industry to provide access to harvest sites. These roads are encountering reductions in bearing capacity and increasingly frequent access interruptions due to excess water in roadbeds combined with climate change and suboptimal construction, management, and maintenance practices. FPInnovations, in collaboration with TenCate Geosynthetics, Presto Geosystems, and Blue Ridge Lumber Inc., is conducting a comprehensive field study aimed at selecting 4 technologies (i.e., moisture wicking and/or high strength woven geotextiles, perforated geocells, and corduroy) and evaluating their ability to improve road strength. This paper describes the testing and site instrumentation (moisture, temperature, and soil pressure sensors). It also discusses preliminary results from performance evaluation (visual characterization, sensor data) of test sections as a comparison to a reference.

RÉSUMÉ
Des centaines de kilomètres de chaussées non revêtues sont construits chaque année par l'industrie forestière canadienne pour permettre l'accès aux ressources. Ces routes sont confrontées à des réductions de capacité portante et à des interruptions d'accès de plus en plus fréquentes en raison de l'excès d'eau dans la structure, combinées aux changements climatiques et aux pratiques de construction, de gestion et d'entretien non-optimales. FPInnovations, en collaboration avec TenCate Geosynthetics, Presto Geosystems et Blue Ridge Lumber Inc., mène une étude de terrain visant à sélectionner 4 technologies (c.-à-d. geotextile drainant et/ou à haute résistance, géocellule perforée, corduroy) et à évaluer leur habilité à améliorer la capacité portante de ces routes. Cet article décrit les essais terrain, sur un site instrumenté avec des capteurs de teneur en eau, des thermistances et des capteurs de pression du sol. Il traite également des résultats préliminaires d'évaluation de la performance (caractérisation visuelle, instrumentation) de chaque section d'essai en comparaison à la section référence.

1 INTRODUCTION

FPInnovations' member companies from across Canada are encountering increasingly difficult road conditions and more frequent seasonal access interruptions because of climate change and complex environmental conditions. Two main types of seasonal interruptions have been identified: those from wet and weak sections during the non-frozen seasons, and those from thawed sections during the winter months. These conditions create access bottlenecks which negatively impact transportation efficiency, fibre access and cost. There is a need for solutions that will improve access in these difficult conditions – which are expected to get worse in the future.

1.1 Background

A wet and weak road section is a section of a resource road, not in a wetland, that periodically or continuously loses its ability to provide access because of excess water flowing to the site and(or) poor ability to drain (Figure 1). Although weak and wet road sections can be any length, this study focuses predominantly on short sections that are described as bottlenecks to road access. Depending on cause(s) there may be few or many wet, weak sections and these can be concentrated in one area or dispersed widely over a road network.

Figure 1. Typical wet and weak bottleneck section

Wet, weak road sections usually occur where a combination of causes interact; these causes typically include moisture-susceptible and/or frost-susceptible soils, presence of surface and/or subsurface water, increased flow of water to the site, and a lack of adequate drainage perhaps due to poor construction and maintenance practices, or under-performing drainage systems.

The immediate consequence of wet, weak road conditions is the creation of an access bottleneck at which heavy trucks have an increasingly challenging time negotiating the section. During this period, travel speeds slow, cycle times increase, and trucks may be damaged as they become immobilized and then are assisted past the section. All phases of operations must be halted at this point while emergency road repairs are made with available equipment and supplies (e.g., bridging the weak section with gravel, corduroy, access mats, etc.). Systematic haul assist may be needed in some cases. The cost of repairs and lost productivity from one bottleneck is not normally excessive; however, the cost can become very considerable if the occurrence of wet, weak sections is widespread or ongoing. Changes to seasonal weather patterns and storm events (climate change) increase the vulnerability of some resource road networks to failures. Unreliable road access requires more intensive management and contingency planning and increases the risk of unscheduled mill shutdowns.

In addition to productivity, deteriorated road sections also may create an environmental liability if sediment-laden drainage from the site impacts nearby fish habitat or other aquatic values.

1.2 Objective

The overall objective of this project is to trial preventive and cost-effective road improvement technologies and practical solutions to provide.

This scientific paper describes study architecture, technologies trialed, and the field installation performed in 2021. It also highlights preliminary results from performance testing.

3 STUDY ARCHITECTURE

For this study, a test site was established to assess the ability of the different solutions and technologies aimed at improving wet, weak roads in summer and winter. The test site was divided into multiple test sections, each equipped with a unique combination of reinforcement and/or insulation technology and monitoring instrumentation.

Four road reinforcing technologies (corduroy, woven geotextile, geocell, and wicking geotextile) are being assessed at this site. The effectiveness of these technologies will be monitored year-long for both summertime performance (drainage and bearing capacity improvement) and wintertime performance.

3.1 Data

This project will rely primarily on long-term temperature and moisture records collected with instrumentation installed in the test road sections. Soil pressure cells installed in the roadbed will also be used to quantify the reinforcement provided by each technology. In addition to the buried instrumentation, a rain gauge and ambient temperature sensor have been installed at the site.

Representative soil samples from the site were analyzed to determine particle size distribution, Atterberg limits, and soil classification. A Dynamic Cone Penetrometer (DCP) with a 60º tip was used to measure in-situ subgrade soil strength.

Embedded pressure cells (1 per test section) were used to collect vertical pressure at-depth as part of static load tests. These tests consisted of a legally loaded gravel truck parking its tridem-drive axle directly above each buried total pressure cell (TPC). The truck's location was varied slightly around the TPC to ensure that the peak pressure values were captured for each technology.

3.2 Analysis approach

A comparative analysis of moisture control and reinforcement will be made between the test sections, including a reference that has no reinforcement technology installed. For a technology to be considered effective, it must demonstrate an increase in bearing capacity and trafficability in its respective test section when compared to that of the reference. This increase in strength and performance are achieved through multiple mechanisms; the most obvious being through reinforcement, but also may include separation, drainage, moisture wicking, and insulation.

Ambient temperature and rainfall sensors located on the roadside datalogger assembly will be used to characterise site conditions to find correlations with the data from the embedded moisture sensors and thermistors.

The strength of each section will be modeled using a combination of field data and the results of the static loading test. A baseline estimate first will be produced for the strength of each section using the soil properties determined by the lab and DCP measurements. The test section models then will be calibrated to agree with the soil pressure results from the loading tests. Feedback from road users and owner will also be gathered at the end of the study.

4 INSTRUMENTATION

4.1 Moisture and temperature

TERROS 10 moisture sensors were used to measure volumetric soil moisture; FPInnovations selected this sensor because of cost, durability, and because, in previous studies, there was negligible between-sensor variation.

44007RC Precision Epoxy NTC thermistors (soil temperature sensors) were used to measure soil temperature. The buried thermistors were arranged on long wires in a sequence of two (vertically spaced apart by 30 cm) or four (spaced apart by 15 cm). As previously noted, a remote datalogger housing (RDH) assembly was installed at roadside (Figure 2). On the RDH, was installed an ambient temperature sensor consisting of a single NTC thermistor inserted within a radiation shield.

An RG6T rain gauge also was mounted on the RDH to record rainfall at each site. The RG6T can only record precipitation as rainfall. The rain gauge can be seen in the RDH assembly also shown in Figure 2.

4.2 Data logger and software

A TSR16 datalogger with 25 channels was used to collect data from the 24 sensors at each site in different configurations. One sensor per channel was connected to the datalogger which was placed inside the metal RDH cylinder. The radiation shield and rain gauge were attached to the RDH as seen below.

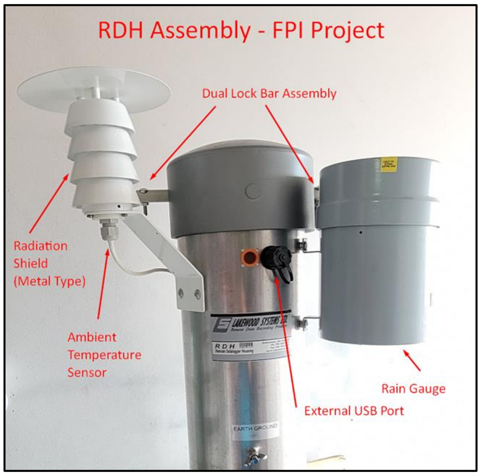


Figure 2. RDH assembly

The software used to program and communicate with the sensors, and process and display data is called *Prolog 4 Datalogger Software*. Lakewood Systems of Edmonton, AB supplied and/or pre-assembled the hardware and software to ensure the system functioned as planned prior to its field installation.

4.3 Total pressure cells

Total pressure cells (TPC) were used to measure the soil strengthening effectiveness of each technology. The TPC soil pressure cells have a 150-mm diameter pressure pad and use vibrating wire technology to measure vertical soil pressures up to 1000 kPa. A LSVW5 – VW datalogger was used to collect the TPC soil pressures. Total soil pressure readings were gathered at the time of construction and during the static loading tests but are not being continuously monitored.

5 TECHNOLOGIES TRIALED

This section describes the 4 technologies that were evaluated at the test site.

5.1 Corduroy

Corduroy is a simple mechanical reinforcement technique that is well known to the forest industry. Locally sourced logs are placed crosswise on the road subgrade and then the road is constructed on top of them. The logs allow for drainage across the road as well as increase its bearing capacity. This can be done during original road construction or as an emergency repair. A non-woven geotextile is often placed on top of the logs to prevent fill materials from filling the gaps in the logs and blocking drainage across the road. Corduroy may also be built with a brush mat underneath the logs (the trial configuration) or with a second layer of logs.

5.2 Woven geotextile

Woven geotextiles are comprised of interwoven polypropylene yarns and depending on location in the roadbed, offer soil and(or) base course confinement and reinforcement. In addition, woven geotextiles can provide drainage, separation, and filtration functions. Mirafi® HP570 (HPW) woven geotextile, manufactured and supplied by TenCate Geosynthetics, was trialed in this study.

5.3 HDPE perforated geocell

Geocells are a three-dimensional geosynthetic made up of interconnected, honeycomb-shaped, cells that offer a high degree of confinement to the material they are filled with. Geocells typically are used for reinforcing critically weak soils. The cell walls of most geocells are perforated to promote lateral drainage (all geocells are open-bottomed to allow vertical drainage). Geocells do not offer separation so they must be used in conjunction with a geotextile placed directly underneath. GW30v6 Alpha Geoweb®, with 15cm cell height, manufactured and supplied by Presto Geosystems, was tested in this study. This is a perforated geocell made of high-density polyethylene (HDPE).

5.4 Enhanced lateral drainage geotextile

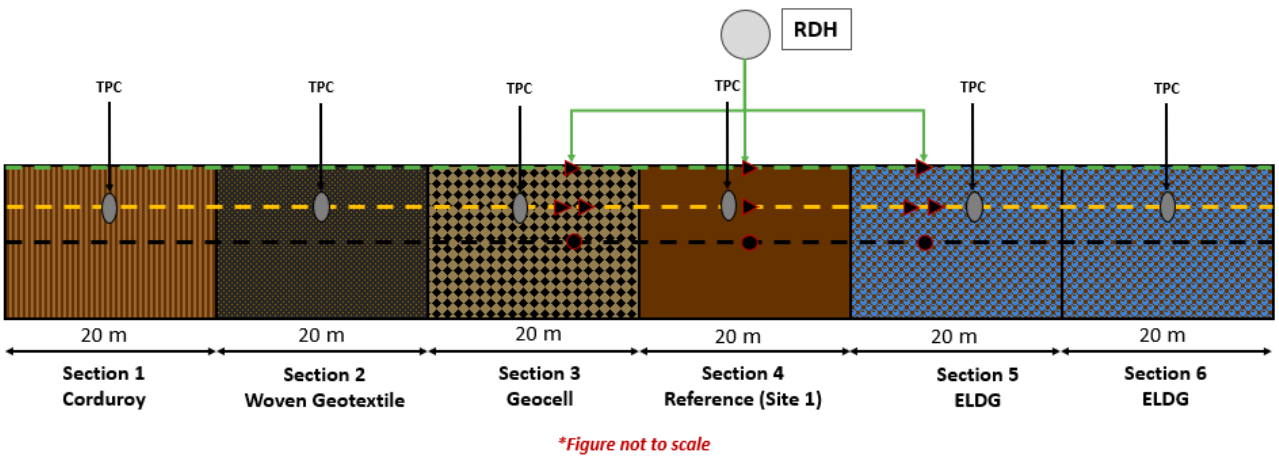
An enhanced lateral drainage geotextile, Mirafi® H_2Ri (ELDG), also manufactured and supplied by TenCate Geosynthetics, was tested in this study. This fabric is a high-modulus woven geotextile capable of separation, filtration, soil reinforcement, confinement, and drainage, as well as moisture wicking. The geosynthetic has special hydrophilic and hygroscopic yarn that provides wicking action in the plane of the geosynthetic, which promotes rapid moisture removal from the road structure. Like other woven geotextiles, it also offers soil and base course confinement resulting in greater load distribution, and robust damage resistance for stress installations.

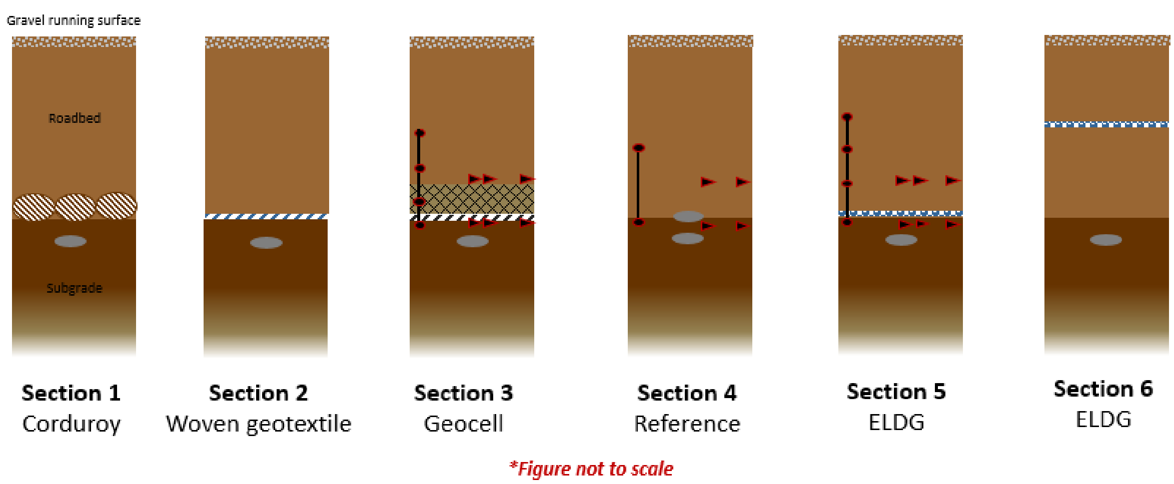
3 FIELD INSTALLATIONS

The test site was located on the Ocelot Road in the Virginia Hills region of Alberta situated between Whitecourt and High Prairie (Figure 3). Construction occurred in August 2021 when daily temperatures reached over 20 ºC and soil conditions were relatively dry. The construction was part of a project to upgrade an inactive section of winter road into an all-season road. Both forestry and energy industry traffic use the road. The road segment was expected to experience wet and weak road issues due to its fine-grained soils and proximity to swamps. Soil lab analysis classified the local soil as a low plasticity clay (CL). Dynamic Cone Penetrometer (DCP) testing at the time of construction revealed the roadbed to consistently have an average California Bearing Ratio (CBR) value of 1.4% indicating an extremely low bearing capacity.

Figure 3. Test site prior to construction and installation

The 120m-long test site consisted of six 20m-long sections one after the other, five with a reinforcing and/or moisture management technology and one as a reference section that was constructed conventionally with no improvement technology. Figure 4 illustrates the plan view and cross section of the test site and sections. It also highlights the relative locations of instrumentation in each section. Instrumentation depth will be confirmed in the next step of the project.





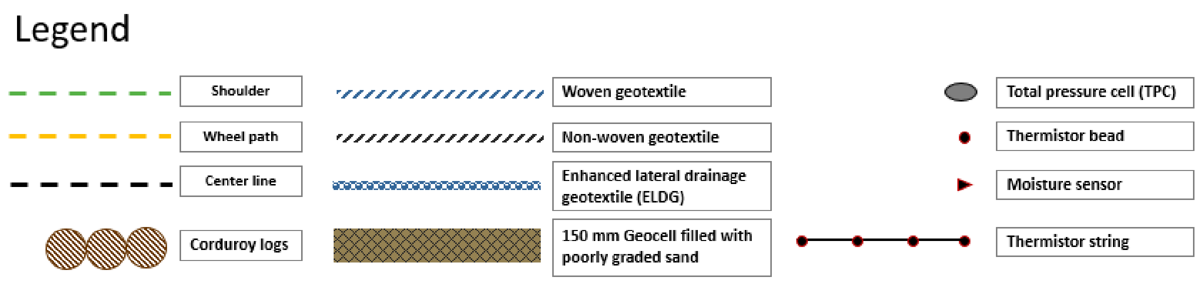


Figure 4. Simplified site plan view and cross sections

The RDH (with datalogger, ambient temperature sensor, and rain gauge) was installed at the midpoint of the reference section (section 4) and 5 m off the road. Moisture and temperature sensors were installed in sections 3, 4, and 5 and were connected to the datalogger at the RDH. Pressure cells were installed in the wheel path of each section with the wiring for each run to roadside where it could be accessed for data collection.

The road's foundation was first prepared with a small bulldozer which skinned off the organics and shaped very shallow V-ditches to either side. After crowning the road subgrade, a tamping foot compactor was used to compact the surface and improve its bearing capacity further. Because this locale was wet and had been glaciated the road builder preferred to not excavate and weaken the in-situ fine-grained soils – hoping to preserve their natural density and strength. Therefore, instead of excavating deep ditches and using the excavated material to build up the roadbed height, a sandier blend of fine-grained soil was excavated from a nearby hill and this material was used to create roadbed lift throughout the wet section.

The roadbed of section 1 was constructed with a brush mat of aspen tops placed on the subgrade, followed by a single layer of 28-32 cm-diameter aspen logs (corduroy), and then capped with the imported soil spread by the bulldozer. No geotextile was placed over the corduroy. Section 2 comprised HPW woven geotextile placed on the shaped and compacted subgrade and then covered with the imported soil spread by the bulldozer.

Figure 5 shows section 3 and its six 2.6m x 9.6m segments of geocell connected together and staked open awaiting filling with sand. A non-woven geotextile was placed underneath the geocell to provide separation. Although weaker than recommended woven geotextile by the manufacturer this material is representative of what forest companies would use with the geocell product. Crusher fines (clean sand) was placed at the end of the geocell layer and then spread into the cells with the bulldozer (being careful not to track on unfilled cells). After filling, a smooth drum compactor lightly packed the sand to stiffen the geocell. Finally, imported soil was placed on top and spread by the bulldozer to form the road.

Figure 5. Geocell laid out and staked (section 3)

Figure 6 shows the ELDG placed in section 6 (the two strips are overlapped by approximately 50 cm). In this section, approximately 0.5 m of lift material was added on top of the shaped and compacted subgrade before laying the geotextile; the reason was so that the reinforcement would be located closer to the surface where traffic-induced stresses are higher. The same ELDG was placed at the subgrade level in section 5, which is more conventional.

Figure 6. ELDG geotextile in two overlapped strips was laid on the raised roadbed of section 6 prior to completing road construction

Figure 7 shows an excavated trench in which instrumentation wires were run from the RDH to sections 3, 4, and 5 prior to burial.

Figure 7. Trenches for instrumentation wiring

TPCs were placed in line with the road wheel path and at 30 cm below the subgrade surface at the center of each 20 m section. Moisture sensors were placed at the wheel path and shoulder of section 3, 4 and 5.

4 PRELIMINARY DATA ANALYSIS

The following sections highlight a preliminary analysis of test site temperature and moisture trends as recorded by on-site instrumentation. Instrumentation consisted of two seasonal configurations—one with more moisture sensors used in summertime and the other with more thermistors used in wintertime. A simple rewiring at the datalogger allows one or the other configuration to be activated. This arrangement allows for the greatest number of sensors to be used for the study of moisture management in the summer and insulating ability in the winter while still respecting the limitations of the datalogger.

4.1 Initial summer temperature trends

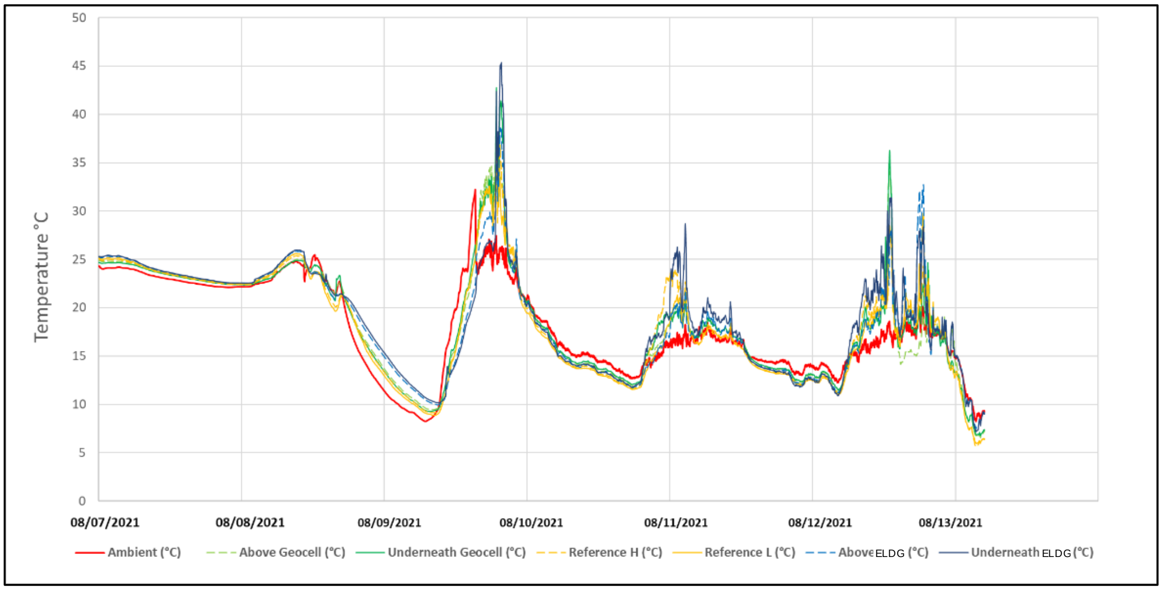
Two thermistors were used in sections 3 (ELDG), 4 (Reference) and 5 (Geocell) for summertime monitoring of site 1 soil temperatures. In sections 3 and 5, a thermistor was placed both above and beneath the reinforcing technology; two thermistors were installed in the Reference section at about the same depth. All thermistors were placed along the road centreline. Figure 7 illustrates temperature trends, including ambient temperature.

The dotted lines denote soil temperatures above the reinforcing technology while solid lines denote soil temperatures below the reinforcing technologies. The thermistors placed below reinforcing technology were at the same depth as those in the Reference section. The trends displayed in Figure 7 were as expected. Daily temperature tends to cycle between warmest in the afternoon and coolest in the early morning. The ambient temperature changes the fastest followed by soil temperatures from shallow depths in the road. The thermistors buried deepest in the road displayed a time lag in recording heating in the morning and cooling in the nighttime. The temperatures from the geocell section appeared to be closer to those in the reference than the temperatures from the ELDG section. The insulating effect provided by each technology will be further investigated with data from winter 2021.

4.2 Initial summer moisture trends

Six volumetric moisture sensors were placed in sections 3 (geocell) and 5 (ELDG) and four were placed in section 4 (Reference) for the summertime set up. These sensors were placed in line with the wheel path or with the road shoulder on one side of the road. In sections 3 and 5, a moisture sensor was placed both above and below the reinforcement technology, while the corresponding two moisture sensors in the Reference section were placed at similar depths. Figure 8 presents the volumetric moisture content in the wheel path for sections 3, 4, and 5 (for a 2-day period in August 2021). No rainfall occurred during this measurement period.

Preliminary results show that, closer to the surface, volumetric moisture content between the three highlighted sections fluctuates in a daily cycle in the same way. This fluctuation follows the changes in temperature, and this is likely from pore water vapour movement. Colder soil temperatures in the early morning seemed to cause a drop in pore water vapour (soil moisture content) below the ELDG and, at the same depth, in the Reference. In contrast, the geocell appears to reduce the drop in moisture content during the cool early morning and this may be because it is a better insulating layer. These general trends will be validated as more moisture data is accumulated from the instrumented sections. The ability of these technologies to dry the upper soil layers in the presence of a high-water table and precipitation will also be assessed.



*Reference H (°C): closer to the surface
*Reference L (°C): at approximately the same depth as thermistors underneath the geocell and H2Ri

Figure 8. Preliminary temperature trends from summertime

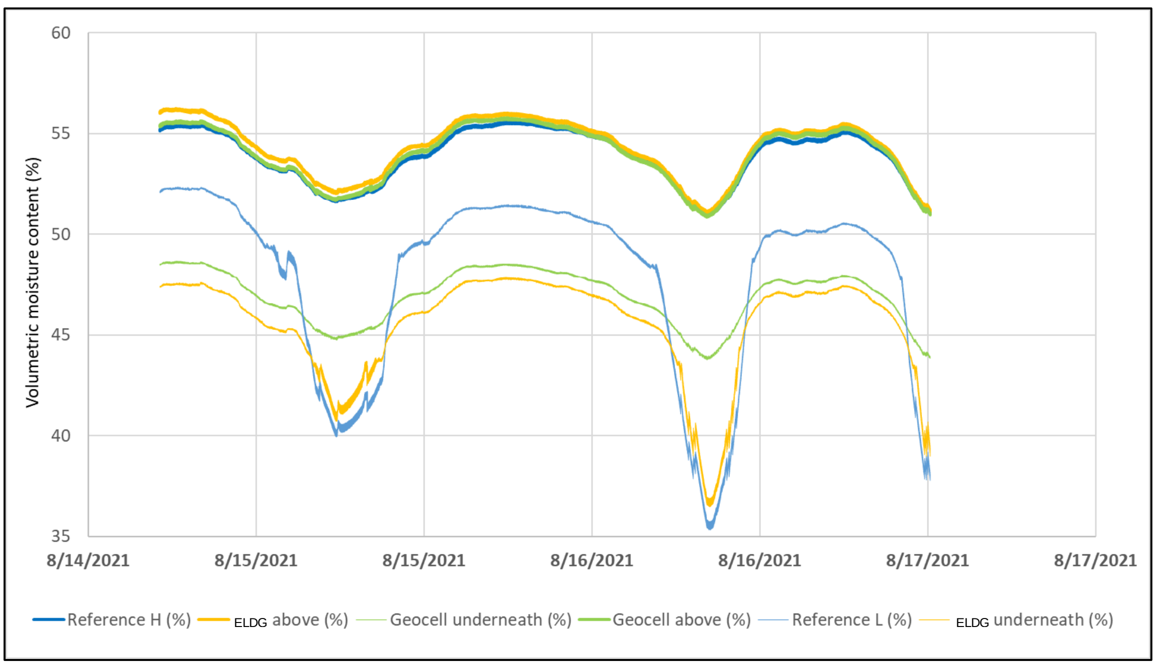


Figure 9. Preliminary moisture trends from summertime

5 DISCUSSION AND NEXT STEPS

This report highlighted the preparation, site and technology selection, construction, instrumentation, and field trial of four potential solutions to summer and winter access problems on wet, weak, forest roads. The visual performance assessment, combined with preliminary trafficking and sensor data analysis have shown promising results from the different technologies that were tested. It remains too early to assess which are the most efficient technologies to address wet weak road challenges both for summer and winter.

The plans for Phase II of this study include:

- A comparative analysis of complete temperature and moisture data
- Bearing capacity evaluation of each technology using light weight deflectometer (LWD), static loading test results, and modeling
- Life cycle cost analyses of the technologies
- Final assessment of technology performance

At the study conclusion, FPInnovations will be able to share expertise to improve road reliability and fibre access.

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